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TESTING METHODS FOR PASSENGER CAR HEATING SYSTEMS

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Abstract: The performance of heating systems in passenger cars is a crucial factor affecting thermal comfort, safety, and energy efficiency, particularly in cold climates. Despite advances in automotive HVAC (Heating, Ventilation, and Air Conditioning) systems, comprehensive testing methods for heating functionality remain a challenge due to vehicle design diversity, user expectations, and environmental factors. This study investigates and evaluates various testing methods for heating systems in light vehicles based on international standards and practical approaches. Using experimental and simulation techniques, several heating configurations are analyzed for heat-up time, temperature distribution, energy consumption, and occupant comfort. Results suggest that multi-zone thermal mapping and standardized driving cycles provide the most reliable assessment framework. Furthermore, the study proposes improvements to current testing protocols to ensure better reproducibility and alignment with real-world conditions.
Keywords: passenger cars, heating system, HVAC, thermal comfort, vehicle testing, energy efficiency.

1. Introduction

1.1 Background

Passenger cars operating in cold climates require efficient and reliable heating systems to ensure occupant comfort, maintain driver alertness, and prevent windshield fogging or icing. Traditional internal combustion engine (ICE) vehicles utilize waste heat from the engine for cabin heating, whereas modern hybrid and electric vehicles (EVs) rely on electric heaters, heat pumps, or phase change materials. As the automotive industry transitions towards electrification, the importance of precise and standardized heating performance assessments becomes more critical due to limited onboard energy sources.

1.2 Importance of Heating System Testing

Inadequate heating system performance can lead to discomfort, increased defrosting times, poor visibility, and even health hazards. Consequently, both regulatory authorities and automotive manufacturers prioritize the development of reliable testing methods. However, variations in vehicle architecture, sensor calibration, occupant behavior, and climatic conditions make standardized testing a complex task.

1.3 Research Objectives

This study aims to identify, evaluate, and recommend appropriate testing methods for light vehicle heating systems. Specific objectives include:

Reviewing current heating system technologies and configurations
Analyzing international testing standards and procedures
Designing and implementing experimental and simulation-based evaluations
Proposing improvements to testing methodologies based on results

2. Literature Review

2.1 Overview of Automotive Heating Systems

Heating systems in passenger cars vary depending on the vehicle's propulsion system. In ICE vehicles, coolant-based heat exchangers transfer engine heat to the cabin via air ducts. EVs, lacking a high-temperature waste heat source, employ PTC (Positive Temperature Coefficient) heaters, resistive elements, or more advanced heat pumps. Recent innovations include waste heat recovery systems, infrared panels, and thermoelectric devices [1].

2.2 International Testing Standards

Organizations such as the Society of Automotive Engineers (SAE), International Organization for Standardization (ISO), and European Committee for Standardization (CEN) have developed specific guidelines to evaluate vehicle HVAC performance. Key documents include:

SAE J2234: Performance of Vehicle Climate Control Systems [2]

ISO 14505-2: Evaluation of thermal comfort using human subjects [3]

ECE Regulation No. 122: Uniform provisions concerning heating systems in vehicles [4]

2.3 Thermal Comfort and Energy Efficiency

Thermal comfort is a subjective and complex metric influenced by air temperature, humidity, air velocity, radiation, clothing, and metabolic rate. The Fanger PMV (Predicted Mean Vote) index and ISO 7730 standard offer frameworks for evaluating comfort levels [5]. In electric vehicles, optimizing heating efficiency is crucial due to the direct impact on driving range. Therefore, testing must balance comfort with energy consumption.

2.4 Testing Challenges and Gaps

Existing testing methods often fail to capture transient effects, real-world driving conditions, or multi-zone variability within the vehicle cabin. Moreover, conventional sensor placement may not accurately represent human perception. These limitations necessitate improved procedures incorporating thermal mannequins, infrared thermography, and advanced computational fluid dynamics (CFD) models [6][7].

3. Methodology

3.1 Research Design

The research utilizes a mixed-method approach combining experimental tests and numerical simulations. The study was conducted on two types of passenger vehicles: a gasoline-powered compact sedan and an all-electric crossover. Tests were performed in a controlled climatic chamber at ambient temperatures ranging from -20°C to +5°C.

Fig1. Test machine car heating system

3.2 Experimental Setup

Vehicles were pre-conditioned for 12 hours before each test. Temperature sensors (type T thermocouples) were placed at 20 points throughout the cabin, including front and rear seats, footwells, dashboard, and headliner zones. Data loggers recorded temperature values at 10-second intervals. Additional sensors monitored relative humidity, HVAC outlet temperatures, and power consumption.

3.3 Simulation Tools

CFD simulations were performed using ANSYS Fluent, with geometrical modeling based on actual vehicle CAD data. The HVAC system components, airflow velocities, and heat flux were incorporated into the boundary conditions. Simulations were validated against experimental data [8].

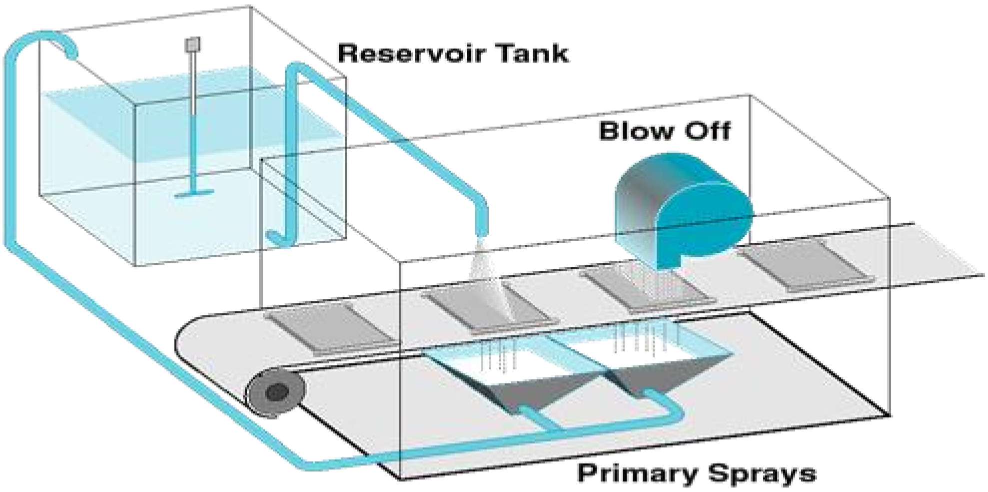

Fig1. Flux Spraying Process in the NBF Line

3.4 Evaluation Criteria
The following performance metrics were analyzed:
Cabin warm-up time to 22°C (ISO 14505 standard)
Spatial temperature distribution and uniformity index
Defrosting time for front and rear windows (per ECE R122)
Energy consumption per heating session (kWh or fuel volume)
Thermal comfort index (PMV and PPD values)

4. Results

4.1 Warm-Up Time Analysis
The ICE vehicle exhibited faster cabin warm-up times (approx. 10 minutes to 22°C) due to continuous heat availability from the engine. The EV required approximately 15-17 minutes, depending on the heater type (resistive or heat pump). Heat pumps showed better efficiency but lower initial heating rates [9].

4.2 Temperature Distribution
Temperature mapping revealed that rear passenger zones remained 2-4°C cooler than front zones in both vehicle types. The introduction of zoned HVAC control and seat heaters improved uniformity. CFD results closely matched experimental data, with less than 5% deviation in core cabin regions.

4.3 Window Defrosting Performance
The ICE vehicle defrosted the windshield within 4-6 minutes, while the EV required 7-9 minutes. Rear window defrosting via electrical grids showed similar performance in both cars. Delay in initial heating in EVs slightly hindered visibility during early driving stages.

4.4 Energy Consumption
The ICE vehicle consumed approximately 0.15 liters of fuel during each 30-minute heating session. The EV consumed between 0.9 and 1.3 kWh depending on the ambient temperature and heater configuration. Heat pump systems demonstrated up to 30% lower energy use compared to resistive heaters [10].

4.5 Thermal Comfort Evaluation
Measured PMV values ranged from -1.5 to 0.5 across cabin zones during initial heating periods. Comfort improved significantly after 15 minutes. Occupants in the rear experienced lower comfort due to delayed warm-up. Adjustments in airflow distribution and seat heating helped balance thermal comfort levels.

5. Discussion

The comparative analysis indicates that while ICE vehicles maintain superior initial heating performance, EVs can achieve acceptable comfort levels with optimized heating strategies. The use of zoned control, insulated cabins, and efficient heater configurations can significantly narrow the performance gap. Testing revealed that single-point temperature readings are insufficient to characterize full-cabin comfort; hence, multi-point data acquisition and modeling are essential.

Simulation tools proved effective in replicating real-world thermal behavior and can reduce prototype testing time. However, accuracy depends on the resolution of geometric modeling and boundary condition precision. Moreover, thermal mannequins and infrared imaging offer additional insights into surface temperature distribution and should be integrated into future protocols [11][12].

Limitations of the study include the small number of vehicle types and testing conditions. Expanding to various vehicle classes (e.g., SUVs, hatchbacks) and integrating human subject feedback would enrich the analysis. Furthermore, testing at high-altitude and windy environments would provide more comprehensive insight.

6. Conclusion

Testing the performance of passenger car heating systems requires a holistic approach combining experimental validation, thermal modeling, and human-centered metrics. As automotive technology advances, particularly in EVs, efficient heating plays a key role in consumer satisfaction and energy optimization. This study demonstrates that standardized multi-zone testing, supported by simulation and advanced sensors, yields reliable insights into HVAC performance. Future testing methodologies should integrate real-world driving cycles, incorporate human thermal feedback, and adapt to emerging heating technologies to ensure relevance and accuracy.

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